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Review

Management of scrap computer recycling in Taiwan

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Abstract

It is estimated that approximately 300,000 scrap personal computers are generated each year in Taiwan [S.-L. Chang, A Study on the Scrap Computer Treatment Cost, Environment Protection Administration of Taiwan, December 1998 (in Chinese)]. The disposal of such a huge number of scrap computers presents a difficult task for the island due to the scarcity of landfills and incineration facilities available locally. Also, the hazardous materials contained (i.e., phosphor coatings of cathode ray tubes (CRTs), batteries, polychlorinated biphenyl capacitors, mercury-containing parts, liquid crystal display, high-lead content CRT funnel glass, and plastic containing flame-retardant bromine, etc.) in the scrap computers may seriously pollute the environment if they are not properly disposed of. Therefore, the EPA of Taiwan declared scrap personal computers the producer's recycling responsibility as of July 1997. Under this decree, the manufacturers, importers and sellers of personal computers have to properly recover and recycle the scrapped computers which they originally sell. On June 1, 1998, a producer responsibility recycling program for scrap computers was officially implemented in Taiwan. Under this program, consumers can bring their unwanted personal computers to the designated collection points and receive reward money. Currently, only six computer items are mandated to be recycled in this recycling program. They are notebooks, monitors, hard disks, power supplies, printed circuit

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boards and main frame shells. This article outlines the current scrap computer recycling system in Taiwan. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Article 10-1 of the Waste Disposal Act (WDA) issued by Taiwan's Environmental Protection Administration (EPA) [2] states that:

If the discarded material, package or container, which is classified as municipal waste has the following properties:

1. It is difficult to be collected and be disposed of.
2. It does not contain readily decomposable substances.
3. It contains hazardous substances.
4. It can be recycled.

and may seriously pollute the environment, they should be recovered and treated properly by its manufacturers, importers and sellers.

This means that if discarded post-consumer products have the above properties, then the government is not responsible for the cleaning and disposal of such products. Instead, the manufacturers, importers, and sellers (MIS) of these products are mandated to properly recover and dispose of their post-consumer products. According to the principles stipulated in Article 10-1 of the WDA, Taiwan's EPA declared the scrap computers as a producer responsibility product on July 5, 1997. Under current regulations of the WDA, the computer manufacturers, importers and sellers have to pay the scrap computer processing fees in support of the implementation of scrap computer recycling in Taiwan. The purpose of this paper is to give an overview of the producer responsibility recycling program for scrap computers in Taiwan.

2. Hazardous materials in scrap computers

Generally, a personal computer consists of three major components: monitor, keyboard and main frame. Among them, the monitor is the largest unit and mainly contains low-recyclable and harmful materials which hinder the success of scrap computer recycling. A typical computer color monitor is composed of a plastic shell, cathode ray tube (CRT), yoke, printed circuit board with integrated circuit (IC), wire, metal, and rubber. Based on a manual-dismantling study, Table 1 presents the composition of a 14-in. Philips color monitor. It can be seen that the CRT unit, which is the largest component, accounts for approximately 50% of the entire monitor. The CRT of a color monitor having an evacuated glass envelope has five major components. These are: (1) the panel glass (faceplate), (2) the shadow mask (aperture), (3) the electronic gun (mount), (4) the funnel glass, and (5) the deflection yoke.

Table 1
Composition of a 14-in. Philips color monitor

Item	Material	Weight (kg)	Wt.%
Shell	Plastic	2.032	17.38
CRT explosion protection unit	Steel	0.213	1.82
CRT unit		6.227	53.27
(Shadow mask)	(Steel)	(0.455)	(3.89)
(Panel glass)	(Glass)	(3.356)	(28.71)
(Funnel glass)	(Glass)	(1.731)	(14.81)
(Gun)	(Steel, glass, copper, plastic)	(0.096)	(0.82)
(Yoke)	(Copper, plastic, steel)	(0.589)	(5.04)
Metal parts	Steel	0.542	4.64
IC board	IC, resin, copper, steel	1.676	14.34
Wire	Copper, plastic	0.661	5.65
Rubber parts	Rubber	0.048	0.41
Plastic parts	Plastic	0.291	2.49
Total		11.690	100.00

Three phosphorescent color coatings (green, blue, and red) are applied to the panel glass to form the monitor screen. The shadow mask is a steel panel with a mask pattern forming a pattern on the screen. After receiving the electrical signals, the electronic gun emits electrons that excite the screen. The glass funnel, which is made of high-lead-content glass, can protect the electron gun and also forms the rear of the CRT. The panel glass is sealed to the funnel glass by a frit seal [3]. In order to protect the user from radiation, the panel glass contains barium (up to 13%) and lead oxide in a small

Table 2
Composition of different kinds of CRT glass [4]

Item	Composition	Basic function
Panel	0–4% lead oxide alkali/alkaline earth aluminosilicate	Optical quality glass; X-ray attenuation; color and tint control
Funnel	22–28% lead oxide alkali/alkaline earth aluminosilicate	High X-ray resistance; viscosity control
Neck	30% lead oxide alkali/alkaline earth aluminosilicate	Thermal expansion match to funnel composition; X-ray absorption
Stem	29% lead oxide alkali aluminosilicate	Expansion match to metal wire feed throughs; X-ray absorption
Gun mount	Potassium aluminosilicate sintering	Crystallization
Frit	70–85% lead oxide zinc borate	Low temperature

concentration; and the funnel glass contains lead oxide (up to 28%) and a small portion of barium. Table 2 presents the composition of different kinds of CRT glass [4]. This Table indicates that the CRT glass may be classified as a hazardous waste due to its high lead concentration [4]. Table 1 shows that the weight of the panel glass is about twice that of the funnel glass. The external deflection yoke is located near the junction between the funnel and the neck which can cause the electronic beams to scan vertically and horizontally over the screen.

In addition to the CRT glass, other components contained in scrap computers may also pose hazardous effects to the environment. For example, the printed circuit boards found in scrap computers face a similar problem because of their content of tin-lead solder and other heavy metals. The phosphorescent color coatings, which contain various heavy metals, may also be considered as a hazardous waste [5]. The plastic shells of computers need special attention if they contain halogenated flame retardants. The liquid crystal display of notebook computers also needs a special attention due to its usage of benzene material for the liquid crystal. Other parts found in scrap computers such as a mercury switch, mercury relay, lithium battery, Ni–H battery, Ni–Cd battery, and polychlorinated biphenyl (PCB) containing capacitor, are also potentially hazardous substances [6–10].

3. Traditional scrap computer treatment

According to statistics issued by the Information Promotion Association of Taiwan, the production of personal computers (PC) in Taiwan in 1998 accounts for 13% of global PC production. The same data show that the installation of domestic computers grew steadily and rapidly over recent years. For example, the number of PC units installed per thousand of the population in Taiwan was 83, 103, 128 and 163 for the respective years 1995, 1996, 1997 and 1998. Accumulated PC installation units for the years 1995, 1996, 1997 and 1998 was 1.773 million, 2.210 million, 2.762 million and 3.545 million, respectively. It is estimated that approximately 300,000 scrap personal computers are currently generated each year in Taiwan [1]. One personal computer consists of one monitor, one keyboard and one main frame.

Although a large quantity of scrap computers is produced, the scrap computer recycling system is not well developed when compared with traditional scrap car recycling system in Taiwan. This is indicated by the fact that there is not a single commercial company existing in Taiwan which specializes in scrap computer recycling. This may be because consumers do not know how to dispose of their unwanted computers and just keep them in the corner of their apartments or throw them away together with ordinary household garbage. Also, economic incentives may not have been high enough to encourage the establishment of a scrap computer recycling system in the past.

Although a specialized computer recycling company does not exist in Taiwan, some local scrap recyclers do take large quantities of retired computers from large organizations such as schools and stock brokers. After receiving the computers, these recyclers manually remove the plastic and iron shell from the PC main frame and monitor. The

CRT obtained from the color monitor can be broken up to recover the steel shadow mask and electronic gun. The recovered plastic and iron can be sold to a local secondary recycling plant. The remaining materials, including the keyboard, mouse, printed circuit board, broken CRT glass with phosphorescent coating, and other low-value electronic parts, are disposed of in landfills or by illegal dumping. These non-recyclable materials may contain harmful substances which can seriously pollute the environment.

Thus, it can be said that the scrap computer recycling system in Taiwan is not well developed and has not been managed well in the past. Moreover, owing to a lack of scrap computer recycling technology, traditional scrap computer treatment processes may pose a severe threat to the local environment.

4. Development of producer responsibility recycling program

In September, 1996, the Republic of China (ROC) EPA announced its intention to develop a producer responsibility recycling program for scrap computers in Taiwan. According to the stipulations in Article 10-1 of the WDA, the EPA decreed scrap computers to be the producer responsibility product on July 5, 1997.

On October 18, 1997, the ROC EPA officially designated scrap computers to include PC main printed circuit boards, PC hard disks, PC power suppliers, PC frame shells, PC monitors and notebook computers. The ROC EPA also decreed that the manufacturers and importers of the aforementioned items are responsible for the later recovery and recycling of their products as of March 1, 1998.

On January 23, 1998, the Scrap Computer Management (SCM) Foundation was formally established by the ROC EPA in order to manage and implement the recycling of scrap computers in Taiwan. This foundation is a semi-official organization directly under the control of the EPA. The main functions of this foundation are to: (1) propose scrap computer processing fees; (2) identify responsible computer manufacturers and importers; (3) establish a scrap processing fee collection system; (4) set up the scrap computer recycling system; (5) select storage and treatment facilities for scrap computer recycling; (6) supervise a third party to audit scrap computer recycling work; and (7) subsidize scrap computer recycling related research projects. Currently, the SCM Foundation plays an essential role in the scrap computer recycling system in Taiwan.

On February 27, 1998, the EPA announced the scrap computer processing fees (see Table 3) for the designated items, as follows: PC main printed circuit board = NT\$75/unit; PC hard disk = NT\$75/unit; PC power supplier = NT\$12.5/unit; PC frame shell = NT\$12.5/unit; PC monitor = NT\$125/unit and notebook computer = NT\$200/unit. This processing fee was effective from March 1, 1998 to December 31, 1998. It is the responsibility of the SCM Foundation to collect this processing fee from the manufacturers and importers of the aforementioned item. According to actual recycling costs, this processing fee will be recalculated and if necessary reset at the end of each year. Proposed new processing fees have to be submitted to the fee evaluation committee, which is organized by ROC EPA for approval.

On May 15, 1998, under pressure from computer manufacturers and importers, the ROC EPA modified its previous announcement by postponing the date of the implementation of scrap computer recycling schedule from March 1, 1998 to June 1, 1998. Thus,

Table 3

Scrap computer processing fees (1998.3.1–1998.12.31)

Source: EPA of Taiwan; US\$1 = NT\$35

Item	Fee (NT\$/unit)
Notebook computer	200
PC main printed circuit board	75
PC hard disk	75
PC power supplier	12.5
PC shell	12.5
PC monitor	125

June 1, 1998 was the official starting date for the implementation of Taiwan's new scrap computer recycling system. This means that since June 1, 1998, all parties responsible for producing or importing the above-listed computer items have had to pay the required processing fees in accordance with the new scrap computer recycling system.

The SCM Foundation, which was formally set up on June 1, 1998, supervises the operation of the computer recycling program. As of the end of 1998, the basic strategies adopted by the SCM Foundation for promoting scrap computer recycling in Taiwan can be summarized as follows.

4.1. Encouragement of consumers to bring in unwanted computers

The SCM Foundation offers reward money for consumers who bring their unwanted computers to designated collection points.

4.2. Establishment of collection points

The SCM Foundation has established many scrap computer collection points island-wide. These collection points mainly consist of computer retailers who are in a good position to receive scrap computers from consumers. The collection points can deal with consumers' reward money on the spot and they can also obtain additional reward money by doing so.

4.3. Selection of storage yards

In order to store the collected scrap computers, the SCM Foundation selected three large-sized storage yards. These selected storage yards are also responsible for transporting the collected computers from collection points to the storage yards. These three storage yards are located in the northern, central and southern part of Taiwan, respectively, to minimize transportation costs.

4.4. Signing of a contract with a third party which shall act as auditor for the scheme

The SCM Foundation selected a third party auditor to audit the actual operations of scrap computer recycling. The main job of this third party is to check and verify the

number of computers recovered and stored in the selected storage yards. On the basis of the auditing reports submitted by this auditor, the SCM Foundation will then pay the appropriate storage fees to the storage yard. This third-party auditing mechanism can greatly reduce the occurrence of fiscal errors within the computer recycling system. However, this mechanism will also increase the cost of scrap computer recycling. Fig. 1

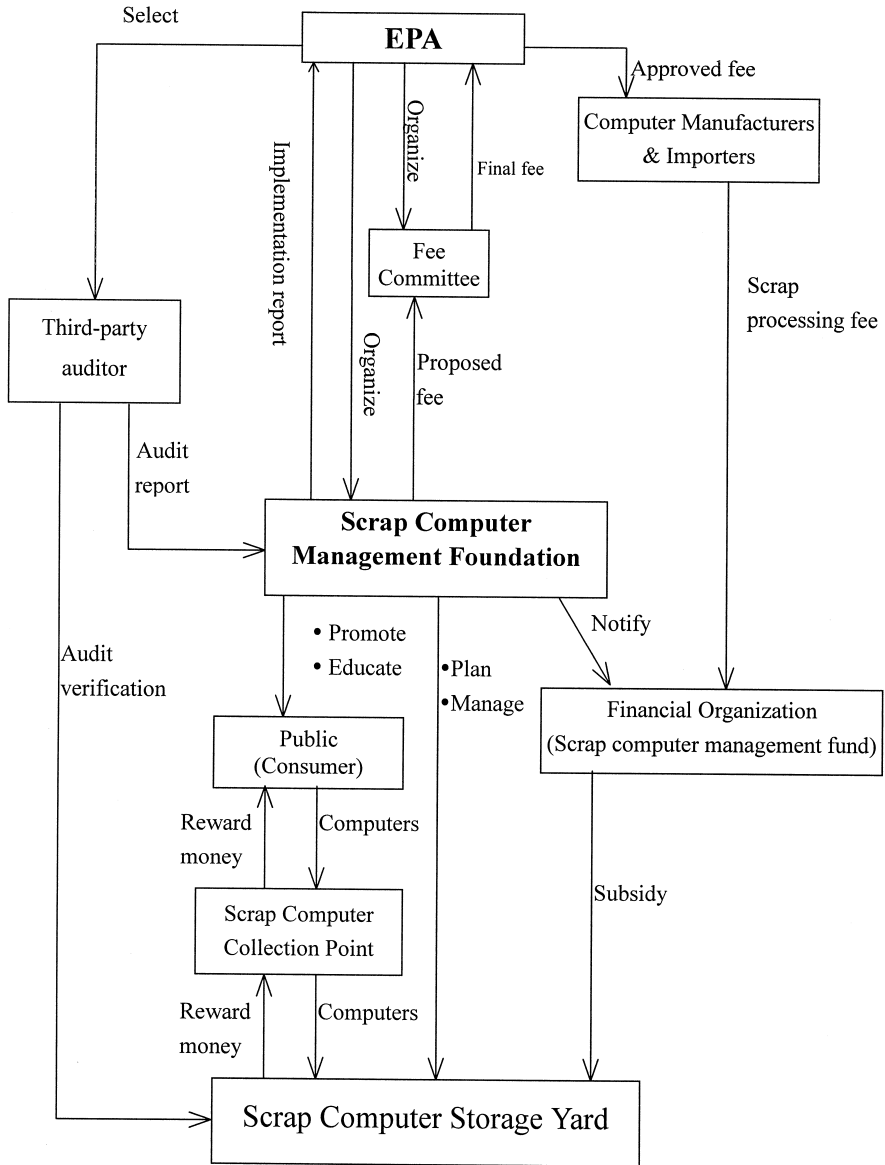


Fig. 1. Diagrammatic representation of the current scrap computer recycling system in Taiwan.

Table 4

Important events in the development of Taiwan's scrap computer producer responsibility recycling system

Schedule	Event
November 11, 1988	Article 10-1 of Waste Disposal Act was issued to mandate a producer responsibility recycling system
September 12, 1996	EPA announced its intention for the development of a producer responsibility recycling system for scrap computers
July 5, 1997	Scrap computer was mandated as a producer responsibility recycling product
October 18, 1997	EPA officially designated scrap computers, to include PC main printed circuit boards, PC hard disks, PC power supplies, PC frame shells, PC monitors and notebook computers
January 23, 1998	Scrap Computer Management (SCM) Foundation was formally established by the EPA
February 27, 1998	EPA announced the scrap computer processing fees for 1998
June 1, 1998	Official starting date for the implementation of Taiwan's new scrap computer recycling system

diagrams the current scrap computer recycling system in Taiwan. Table 4 lists the important events which occur during the development of scrap computer's producer responsibility recycling program.

5. Current implementation status

On June 1, 1998, the SCM Foundation established a recycling network to promote scrap computer recycling in Taiwan. Owing to a lack of proper treatment facilities and recycling technologies for recycling scrap computers, this network focuses only on the collection and storage of scrap computers.

Table 5

Consumers reward money for scrap computers

Item	Reward money (NT\$/unit)
Notebook computer	100
PC main frame (shell + main printed circuit board)	100
PC monitor	100

Source: EPA of Taiwan; US\$1 = NT\$35.

Table 6
Collection points' reward money for scrap computers

Item	Reward money (NT\$/unit)
Notebook computer	50
PC main frame (shell + main printed circuit board)	60
PC monitor	70

Source: EPA of Taiwan; US\$1 = NT\$35.

By the end of 1998, the SCM Foundation had contracted more than 400 collection points to receive scrap computers from consumers. At the collection points, the consumers immediately receive their reward money. Currently, a consumer can receive NT\$100 for bringing in a notebook computer, NT\$100 for a PC main frame (containing at least the PC shell and the main printed circuit board) and NT\$100 for a PC monitor. Details of the consumer reward money for each item are listed in Table 5. If the consumer has more than 12 units of the declared items (i.e., each notebook computer, PC main frame and PC monitor can be counted as one unit), then the consumer can request the collection point to have collecting trucks of the designated storage yard to come and pick up these items directly.

After receiving more than 12 units of the declared computer items, the collection point can inform the designated storage yard to come and pick up these collected items. In doing so, the collection point can receive from the storage yard its reward money and the money which is prepaid to the consumer. At the present time, the collection point can receive NT\$50 for every notebook computer, NT\$60 for every PC main frame (shell + main printed circuit board) and NT\$70 for every PC monitor. Details of the collection reward money for each item are listed in Table 6.

To date, three storage yards, located in the northern, central and southern parts of Taiwan, respectively, have been selected to transport the collected computer items from collection points to their own storage yards. The storage yards are also responsible for storing and managing the collected items until scrap computer treatment facilities are

Table 7
Scrap computer storage yards' operation costs

Item	Cost (NT\$/unit)		
	Location		
	Northern yard	Central yard	Southern yard
Notebook computer	31	30	31
PC main printed circuit board	38	36	38
PC hard disk	55	34	35
PC shell	17	16	17
PC power supplier	13	12	13
PC monitor	76	72	76
Total	210	200	210

Source: EPA of Taiwan; US\$1 = NT\$35.

Table 8
Number of scrap computers recovered in 1998

Item	Number (Unit)					
	Month					
	6	7	8	9	10	Total
Notebook computer	11	32	98	31	53	225
PC main frame	3866	5987	6962	6067	7002	29,884
PC monitor	10,343	10,513	10,813	13,144	16,907	61,720
Total	14,220	16,532	17,873	19,242	23,962	91,829

Source: EPA of Taiwan.

available in Taiwan. After a certain period, the third party auditor will be called to conduct an on-site inspection to verify the actual number of computers stored in the storage yards. According to the results of this audited report, the SCM Foundation shall pay the necessary operational fees to the storage yards. This fee is determined by calculating the actual transportation and storage costs for each declared item stored in the storage yards. Details of the fees for each declared item in the different storage yards are tabulated in Table 7.

According to the ROC EPA's report [1], from June 1998 to October 1998, a total of 29,884 units of PC main frames, 61,720 units of PC monitors and 225 units of notebook computers were recovered. Table 8 shows the number of the different items recovered in each month. Table 8 indicates that the number of recovered notebook computers was much less than other recovered items. It also shows that the number of recovered PC monitors was about twice the amount of recovered PC main frames. This phenomena reflects the growing popularity of the computer DIY market in Taiwan (for example, most consumers can easily obtain new main printed circuit boards to upgrade their old PC main frames). From Table 8, it can be seen that the number of various recovered items steadily increased in the last few months of 1998. This indicates that the newly developed scrap computer recycling system in Taiwan is working well.

However, due to a lack of scrap computer recycling facilities in Taiwan, all the collected scrap computers are currently being stored in the storage yards without being processed any further. Thus, the most urgent task for the SCM Foundation now is to arrange for the establishment of scrap computer recycling facilities in Taiwan so that scrap computer recycling can really be implemented.

6. Scrap computer treatment guidelines

Compared with other traditional post-consumer products (i.e., glass bottles, steel cans, scrap cars, etc.), the scrap computer is a relatively new waste. The experience with treatment of scrap computers is quite insufficient among the local recyclers. In order to promote the establishment of scrap computer recycling facilities in Taiwan, the EPA of Taiwan proposed "Scrap Computer Treatment Guidelines" for the local recyclers who are interested in establishing such facilities. These proposed "guidelines" mainly focus

on how to treat the potential hazardous substances contained in scrap computers to avoid possible damage to the environment. The main features of these guidelines are outlined below:

1. Landfill or incineration of scrap computers shall be avoided.
2. The phosphorescent coatings which have been applied to the glass panel of CRT must be removed before the CRT glass can be further treated.
3. All the batteries (i.e., Li, Ni–Cd, Ni–H) must be removed by non-destructive means for proper treatment.
4. All the capacitors (possibly containing PCB) which have a diameter greater than 1 cm and height larger than 2 cm must be removed by non-destructive means for proper treatment.
5. All the mercury-containing parts must be removed by non-destructive means for proper treatment.
6. The CRT must be ventilated before it can be stored inside the building.
7. The high-lead content funnel glass of the CRT must be properly treated.
8. The liquid crystal display of notebook computer must be removed by non-destructive means for proper treatment.
9. Plastic that contains flame-retardant of bromine shall be treated properly.

The aforementioned hazardous substances which are removed from scrap computers must be treated properly. At the present time, there is no single treatment facility in Taiwan which has the capability to treat removed substances such as batteries, PCB capacitors, mercury-containing parts, and liquid crystal displays. Thus, some of the removed hazardous substances may have to be delivered to foreign treatment facilities to be treated properly. Table 9 shows the potential disposal means for the aforementioned hazardous substances in Taiwan. For example, the phosphorescent coating can be treated by solidification and stabilization technologies. The high-lead content CRT funnel glass can be sent back to CRT glass manufacturer for re-smelting into new funnel glass. The plastic shell can be incinerated in the incinerator or recycled in the plastic recycling plant.

Table 9

Potential disposal means for the hazardous substances removed from scrap computers in Taiwan

Hazardous substance	Potential disposal means
Phosphorescent coatings	(1) Solidification; (2) Stabilization
Batteries (Li; Ni–Cd; Ni–H)	(1) Out-of-country treatment
Mercury-containing parts	(1) Out-of-country treatment
High-lead content funnel glass	(1) CRT glass recycling; (2) Glass products; (3) landfill
Plastic containing flame retardant bromine	(1) Plastic recycling; (2) incineration; (3) landfill
PCB capacitors	(1) Out-of-country treatment
Liquid crystal displays	(1) Unknown

7. Conclusions

On July 5, 1997, Taiwan's EPA decreed scrap computers as a producer responsibility product. Currently, the term "scrap computers" covers PC main printed circuit boards, PC hard disks, PC power suppliers, PC frame shells, PC monitors and notebook computers. The manufacturers and importers of the aforementioned items are responsible for the later recovery and recycling of their products in Taiwan. At the present time, the SCM Foundation established a recycling network to promote scrap computer recycling in Taiwan. By the end of 1998, this recycling network consisted of more than 400 collection points and three regional storage yards. However, due to a lack of proper treatment facilities for recycling scrap computers, this network focuses only on the collection and storage of scrap computers. Thus, currently the top priority for the SCM Foundation is to arrange for the establishment of scrap computer recycling facilities in Taiwan in order to complete the system's infrastructure.

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